DURABILITY OF CONCRETE - CONSTRUCTION FACTORS

INTRODUCTION

Durability of concrete depends on a multitude of factors, and is no longer considered simply a by-product of satisfactory compressive strength alone. Some factors, which may influence durability, include errors in construction, design faults such as bad detailing, exposure conditions and the overall quality of the concrete itself. The interaction between the quality of the concrete and its environment must be a focal consideration. Poor and inexperienced workmanship, insufficient supervision and use of inappropriate specifications and standards should be avoided. Every effort should be made to ensure that the construction process is designed, monitored and executed to the required specification so that long term quality and performance of in-situ concrete is assured.

This technical note provides a general overview of key factors which should be considered during the construction phase. Adherence to the general principles outlined in this Technical Note will ensure that the resulting concrete will fulfill its structural function and maintenance costs will be minimised over the design life.

PROPERTIES OF CONCRETE

Strength and durability are the two main properties of hardened concrete. Concrete must be strong enough to satisfy structural and safety requirements and durable enough to resist deterioration under service conditions. In the plastic state, workability and cohesiveness are desirable properties. Workability relates to the ease of mixing, handling, placing, compactability and ability to finish the concrete. Cohesiveness is a measure of how well the concrete resists segregation.

CONCRETE MIX DESIGN

The concrete mix should be designed such that the required durability and strength and other requirements of the hardened and plastic concrete are achieved. Concrete mix designs must be supported with all relevant mix design details including documentary evidence of previous performance and test results including compressive strength, VPV (volume of permeable voids), drying shrinkage, soluble salts and alkali aggregate reactivity. Other required information includes method of placement, cover to the steel reinforcement and proposed curing methods. It must be emphasised that concrete suppliers may not have all testing information at hand for a particular concrete mix design and trial mixes may have to be undertaken to produce such test results. The process of conducting trial mixes and generating test results may take between 3 to 10 weeks. It is therefore recommended that supervising personnel ensure that contractors are aware of these requirements well in advance in order to avoid any project delays or contractual disputations. It is advisable that the concrete mix design requirements are highlighted to contractors at post-tender review meetings and the first site meeting.

SUPPLY OF CONCRETE

Water in excess of the design amount has a detrimental effect on the strength and durability of concrete. The higher the water/cement (w/c) ratio the weaker is the cementitious paste which binds the aggregate together. The residual water leaves interconnected air voids in the hardened concrete. The concrete supplier should ensure that the moisture content of both sand and stone is determined on a regular basis at the batch plant and allowed for in the total volume of water. Moisture content of aggregates constitutes a significant proportion of the total water and therefore any non-allowance can adversely affect the quality, VPV and therefore durability of concrete. No water additions should be allowed after samples have been taken on site and discharge has commenced. The requirement for recording all water components on concrete delivery dockets is intended to eliminate the unauthorised or excessive addition of water in concrete.

COVER TO REINFORCEMENT

The depth of cover is the shortest distance between the surface of a concrete member and the nearest surface of the steel reinforcement (usually ligatures or stirrups). A relatively thick, dense and impermeable concrete cover will best ensure long-term durability and service life. The cover concrete provides the alkaline environment to protect steel from the ingress of aggressive agents and corrosion. The amount of cover is dictated by exposure conditions and must also satisfy structural design and fire protection requirements as well as the ability to place and compact the concrete within the cover zone. It is critical that specified cover is achieved on site.

FORMWORK

Formwork should provide the shape, lines and dimensions required in the finished concrete. Formwork must be rigid, watertight, braced and tight so that it maintains its position and shape during casting of the concrete. Forms must be well sealed to stop the cement paste from leaking out as this may lead to porous or cracked concrete and to unsightly surfaces. The faces of forms must be capable of providing the required surface finish and they must be kept clean, undamaged and treated with a suitable release agent.

STEEL REINFORCEMENT

Reinforcement fabrication and bending should be in accordance with specified tolerances. All reinforcement should be placed accurately in the positions shown on the drawings, with the specified cover. Reinforcement should be securely held to prevent displacement during placing and compacting. Reinforcement supports must be capable of withstanding imposed loads during the concrete placement process; they must be the right size and must not move so as to maintain the required cover. The accuracy of the placing of steel reinforcement should be checked progressively as the work proceeds to ensure timely corrections of mistakes and avoid unnecessary remedial measures due to lack of cover concrete.

PLACING CONCRETE

Concrete should be discharged into the forms within 60 minutes of batching. The low discharge time requirement for VicRoads concrete (ref. 1) is related to the higher amounts of cementitious content (i.e. faster hydration reactions) compared to normal/commercial class concrete. The time of mixing, arrival on-site and time of discharge should be recorded on the delivery docket and be kept under control.

Placement should be undertaken by acceptable means and concrete should not be dropped from heights greater than 2 metres to avoid segregation. Discharge fall should be kept to a minimum and if necessary drop chutes can be used. Vibrators should not be used to make concrete flow. The mortar will flow away from the stone and cause segregation. Start concrete placement from the lowest corner of formwork. Place each load of concrete into the face of the previous plastic concrete, not away from it. Deposit in horizontal layers and compact before the next layer is placed. Place concrete as near as possible to its final position.

COMPACTION

Compaction is critical and directly influences the strength and durability of concrete, particularly the outer layer or cover zone. The contractor must have in place quality procedures giving full details of the method of placement, number, size and frequency of vibrators (i.e. internal, external) and spacing of vibration insertions etc.

Compaction removes entrapped air from the freshly placed concrete. The strength of concrete (and durability) is affected by the amount of air present (4 to 5% air in the concrete can result in a 20% loss of strength and more than 20% increase in VPV). Good compaction reduces air to less than 1%.

Vibration should be applied to the full depth of each layer and extended into the top 100 mm of the underlying layer to ensure satisfactory knitting and mixing of successive layers in order to prevent any cold joints or inadequate compaction. Internal vibrators should be inserted vertically at spacings not exceeding the manufacturer's stated zone of influence (i.e.300 - 500mm spacing). Touching or hitting formwork or reinforcement should be avoided. Damaged formwork can result in unsightly dark stains on concrete surfaces and of course hitting steel can result in loss of the all-important concrete cover.

HOT WEATHER CONCRETING

Problems associated with hot weather concreting have the potential to adversely affect strength, durability and surface finish. Hot weather can be taken to mean any combination of high air temperature, high concrete temperature, low relative humidity, solar radiation and wind velocity. These can impair the quality of both the fresh and hardened concrete or otherwise result in abnormal concrete properties. Hot weather concreting increases the danger of cold joints forming. This is when plastic concrete is placed against concrete that has set and started hardening. It is better to form a construction joint if a cold joint is likely to form. A number of precautionary measures can be undertaken and be part of the contractor's quality procedure (ref. 2).

FINISHING

Finishing of concrete can be done by using screeding, floating or troweling. Final finishing should only begin when the bleed water, which comes to the surface following concrete placement, dries up. Finishing any concrete area with free surface water will produce a weak friable, dusty surface and laitance. Drying up surface water with cement will produce a weak surface and cause cracking. Hand or power floating helps to smooth irregularities, embed large aggregate and close minor cracks, which can occur as the surface dries out. Hand floats produce a rougher texture. Steel trowelling is done after floating is finished. It provides a smooth, dense and hard surface, which is also durable and easy to clean, although slippery when wet. Trowelling can be done by hand or power trowel.

EVAPORATION OF WATER FROM FRESHLY PLACED CONCRETE

In order to ensure the early quality of the concrete and prevent potential plastic shrinkage cracking and a weak and porous cover concrete, it is important to minimise the evaporative moisture losses from the freshly placed and unprotected concrete until curing is implemented. VicRoads standard specification 610 requires that where the value of the rate of evaporation exceeds 0.50Kg/m^2/hour, the contractor must take precautions, such as the application of an aliphatic alcohol based evaporative retarding compound or controlled fog spray, to minimise evaporative moisture losses. To establish the evaporation rate, the contractor must measure the wind speed, air and concrete temperatures and relative humidity one metre above the as placed concrete. If the contractor is not able to adhere to good working practices, aliphatic alcohol should be applied immediately after initial screeding.

CURING

Curing assists the concrete to develop its required strength, impermeability (i.e. low VPV) and durability. It assists in the development of a hard surface and reduces evaporation, which results in shrinkage and possible cracking (ref. 3). Commencement of curing at the earliest time and for the required period is vital and one should not wait until the whole job is complete before starting curing. Curing must start immediately progressive finishing of concrete or within 1/2 hour of removal of formwork and continue uninterrupted for the specified periods. VicRoads specification 610 allows the use of several curing methods and possible combinations of these. Various curing compounds are allowed subject to satisfying a minimum efficiency index of ³ 90% as per AS 3799. In addition, the specification requires that the application rate of curing compounds be calculated using felt mats placed on the concrete surface to ensure that the minimum efficiency index is achieved in practice. Curing compounds are allowed on concrete decks or slabs only if aliphatic alcohol is used prior to curing.

TEMPERATURE DIFFERENTIAL ACROSS CONCRETE MEMBERS

Excessive temperature differentials (i.e. ³ 20 ^{o}C) during the curing process across a concrete element can cause the build up of internal stresses and hence detrimental thermal cracking to the concrete element at an early age. This, coupled with potential shrinkage cracking and other restraining effects could result in more severe cracking of concrete components. VicRoads specifications require the contractor to monitor temperature differentials and implement special precautions, such as the use of thermal insulation blankets, if the temperature difference is likely to exceed 20 ^{o}C.

DIMENSIONAL TOLERANCES

Monitoring of compliance in relation to dimensional tolerance limits for the final product (ref.1) is an important function to be undertaken by the contractor and therefore relevant quality procedures should be put in place. Dimensions outside allowable tolerance limits can have adverse effects on the final product, including potential unsatisfactory structural consequences, reduction in concrete cover and therefore long-term durability.

CRACKING OF CONCRETE

Cracks wider than 0.1mm require further examination to be undertaken to establish the type, cause and extent of the crack and where necessary undertake preventative and/or remedial action. For further details of cracks in concrete refer to Technical Note No. 38 (ref.4) of this series.

REFERENCES

1. VicRoads Structural Concrete Specification, Section 610, 2000.
2. Guide to Concrete Construction, HB64, SAA and C&CAA, 1994.
3. Technical Bulletin No.42, Curing of Concrete, GeoPave, VicRoads, 2000.
4. Technical Note 38, Cracks in Concrete, GeoPave, VicRoads.

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